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Duckbill elastomer check valve use effects on domestic wastewater discharging marine outfalls initial dilution performance improvement

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ABSTRACT

Most of the domestic wastewater discharging marine outfall diffusers have simply opened circular ports on the diffuser pipe wall. In order to protect the diffuser from seawater intrusion and clogging by sediments during lower flow rate periods, “duckbill” check valve (DBV) can be mounted on circular ports. Because of the DBV use instead circular ports at the same conditions, jet velocity at port could be increased. It was reported in some of the studies that the initial dilution was also increased in changed diffusers with DBVs. In this study, the initial dilution estimations of multiport diffusers were compared before and after DBV mounted conditions of horizontally opened circular sharp edged ports on the thin pipe wall. For $Q = 0.5\ \mathrm{m^3/s}$ design flow rate, t = 30-year lifespan, H = 20–50 m port depths and, $\rho_a = 1{,}015\text{–}1{,}035\ \mathrm{kg/m^3}$ receiving water densities, 12 different diffusers with $d = 150$ mm diameter sized circular ports were designed. With the same total head, all diffusers were converted to 150-mm DBV nozzles. All hydraulic parameters and initial dilutions of before and after DBV usage were recalculated from the literature data for line source in this study. Dilution comparisons for the end of the project were shown that all DBV used results were lower than circular port results as ΔS (%) from −0.19 to −19.18 ranges. Except for two of the lower density values at the shallowest port depths, ΔS (%) had similar results for project start year.

Keywords: Duckbill check valve; Initial dilution; Marine outfall; Domestic wastewater; Sharp edged port

1. Introduction

Marine outfalls with multiport diffusers are widely used for domestic wastewater discharges. Most of the diffusers have simply opened circular ports on the diffuser pipe wall. A circular port maintains the shortest passage for effluent discharge from internal side of diffuser pipe into the marine environment. Because of the short trajectory of the effluent, open ports have lower levels of energy loses, comparing with other types of discharging nozzle arrangements, such as risers and other bending and contracting sections including discharge points. Sharp-edged port, which is a cylindrical hole in the diffuser pipe, has types regarding diffuser pipe wall thickness, t_w and port diameter, d. Thin-walled sharp-edged port has $t_w/d < 0.5$ [1]. On the other hand, $t_w/d > 1.0$ condition

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is called as thick-walled sharp-edged port. These ports have less energy losses because of the shortest trajectory of wastewater jets.

Under fully flowing conditions of diffusers with designed project flow rate, there is no problem about maintaining a proper wastewater flow regime. However, during lifespan of these systems, their flow rates are very changeable. Flow rate will be lower than designed project flow rate, because of the low wastewater producing small population. In order to protect the diffuser from seawater intrusion and clogging by sediments, an elastomer nozzle, duckbill check valve (DBV), can be mounted on circular ports [2]. Because of the increased wastewater jet velocity at ports, u, after DBV use, it was reported by Duer [3] that the initial dilution could be increased in changed diffusers. On the other hand, many of the successful initial dilutions reported studies about DBVs, such as Sezgin [4] reported the increased initial dilution in cold water discharge. Nemlioglu and Sezgin [5] also reported the similar situation for cold water discharge, as well under different conditions. Roberts and Duer [6] reported the improved cold water initial dilution in closed tanks, as well. However, because of the complex structure of DBVs, Lee et al. [7] experimentally described hydraulics of some of the DBVs. Singular port application has successful dilution results. But Duer and Salas [8] reported that the initial dilution decreases the possibility of the multiport diffuser circular port to DBV used condition at deeper locations than H = 20-m port depths. The risk of the initial dilution loss in DBV converted diffusers, needs to be performed additional researches on this problem. In this study, the initial dilution levels of multiport diffusers were theoretically compared before and after DBV mounted conditions of horizontally opened circular sharp-edged ports on the thin pipe wall.

2. Materials and method

In this study, the initial dilution levels of multiport diffusers were estimated in order to compare before and after DBV mounted conditions of horizontally opened circular sharp-edged ports on the thin pipe wall. The design parameters of this study were selected as lifespan, t = 30 years, design flow rate, $Q = 0.5\ m^3/s$, port depths, H = 20, 30, 40, and 50 m, effluent density, $\rho_0 = 1{,}000\ kg/m^3$, and receiving water densities, ρ_a = 1,015, 1,025, and 1,035 kg/m^3. Sharp-edged and at thin-walled pipe circular port including 12 separate diffusers with d = 150-mm port diameter were designed. Hydraulic calculations of diffusers were performed according to Rawn et al. [9] study. Total energy at the last port E_N (flow rate feeding section) value was also calculated for per diffuser. Diffusers assumed horizontally located to the seabed. Darcy–Weisbach friction factor, $f = 0.02$, distance between subsequent ports, $l = 5$ m, and main pipeline length to diffuser, L_{main} = 1,500 m were selected. According to the chosen design flow rate, for t = 30-year lifespan served population was defined as N_{30} = 172,800 persons. For the first-service year $t = 0$ year, served population was defined as N_0 = 71,192 persons, and flow rate $Q_0 = 0.206\ m^3/s$. The limitation values of velocity in diffuser pipe, v were adopted from Grace's study [10] as between 0.6 and 0.9 m/s.

The initial dilutions of designed diffusers with circular ports, $S_{circular}$ (dilution, $S = c_0/c$, where c_0 is the source pollutant concentration and c is the diluted local pollutant concentration) were estimated from Fan and Brooks experimental results for line source [11]. With the same total head, all diffusers were converted to 150-mm DBV nozzles. Based on Lee et al. [7] experimental study, all hydraulic parameters were recalculated. Then, all dilutions were recalculated (S_{DBV}). Dilution comparisons for the end of the project were calculated from $\Delta S\ (\%) = 100 \times (S_{DBV} - S_{circular})/S_{circular}$. All dilution values were compared using $S_{circular}$ base value in their own operational year and their own E_N total head values. E_N, u, N_a and S parameters were performed for Q_0 flow rate and calculated for t = 0 year and t = 30 years. Because of $Q_{30} > Q_0$, all calculated parameters were shown difference for t = 0 year and t = 30 years. Active port number, N_a, values were defined from diffuser hydraulic calculations. Inactive port number, N_i, values were calculated from $N_i = N - N_a$ in this study.

3. Results and discussion

The original design parameters of horizontally opened circular ports including diffusers were summarized in Table 1 for the end of lifespan, t = 30 years. After DBV use, all dilutions were decreased as ΔS (%) from −0.19 to −19.18 ranges when comparing the circular ports. By increasing H and ρ_a levels ΔS (%) values were decreased as seen in Table 1. The minimum difference as ΔS (%) was calculated in H = 20 m, $\rho_a = 1{,}015\ kg/m^3$, and E_N = 1.18 m in DBV1 case. On the other hand, the maximum difference ΔS (%) was found as H = 50 m, $\rho_a = 1{,}035\ kg/m^3$, and E_N = 2.61 m in DBV12 case. All wastewater jet velocity at port values was also given in Table 1. Their values in DBV condition were always found to be 2.3 times higher than circular ports. However, the increased jet velocities were resulted in the decreased dilution levels because of the shortened diffuser lengths. In

Table 1
Circular port and duckbill mounted diffuser characteristics summary for the end of lifespan (t = 30 years)

Nozzle type			Circular port				Duckbill check valve					Comparison	
Case no.	ρ_a (kg/m^3)	H (m)	E_N (m)	u (m/s)	N_a	S	E_N (m)	u (m/s)	N_a	N_i	S	ΔS	ΔS (%)
DBV1	1,015	20	1.18	2.82	11	98.93	1.18	6.61	7	4	98.74	−0.19	−0.19
DBV4	1,015	30	1.33	3.00	10	141.49	1.33	7.02	7	3	126.69	−14.80	−10.45
DBV7	1,015	40	1.48	3.17	9	177.75	1.48	7.40	6	3	152.64	−25.11	−14.13
DBV10	1,015	50	1.61	3.34	9	210.00	1.61	7.76	6	3	176.91	−33.09	−15.75
DBV2	1,025	20	1.38	3.07	10	109.36	1.38	7.19	6	4	101.87	−7.48	−6.84
DBV5	1,025	30	1.61	3.35	9	151.92	1.61	7.78	6	3	131.56	−20.35	−13.39
DBV8	1,025	40	1.86	3.60	8	189.04	1.86	8.35	6	2	158.79	−30.24	−15.99
DBV11	1,025	50	2.12	3.85	8	223.97	2.12	8.92	5	3	183.23	−40.73	−18.18
DBV3	1,035	20	1.58	3.30	9	117.02	1.58	7.68	6	3	103.52	−13.49	−11.53
DBV6	1,035	30	1.92	3.66	8	157.46	1.92	8.50	5	3	134.15	−23.30	−14.80
DBV9	1,035	40	2.28	3.99	8	196.26	2.28	9.25	5	3	161.43	−34.82	−17.74
DBV12	1,035	50	2.61	4.29	7	231.87	2.61	9.91	5	2	187.39	−44.47	−19.18

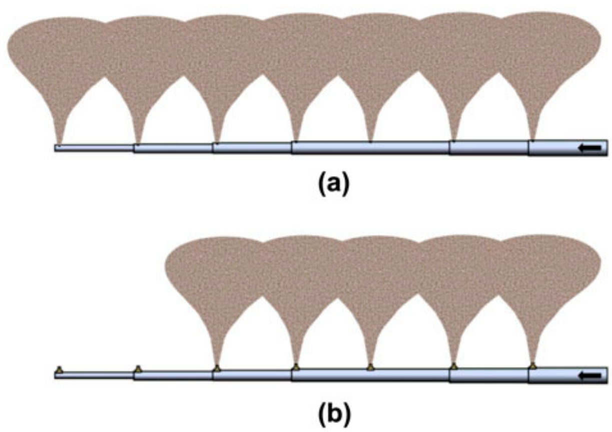

Fig. 1. Plan view of DBV12 case t = 30-year diffuser: (a) circular ports and (b) DBV ports.

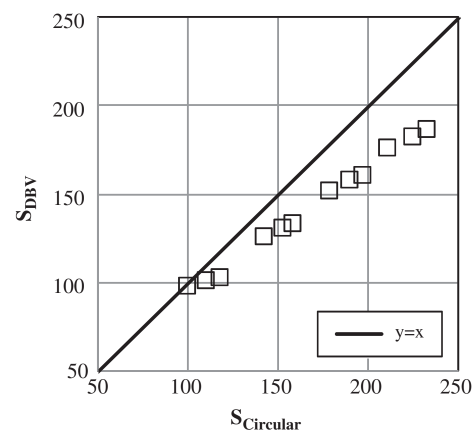

Fig. 2. Dilution comparison of circular vs. DBV port used conditions of same diffusers for t = 30 years.

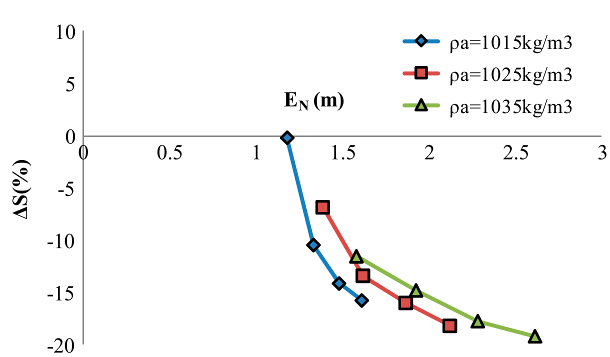

Fig. 3. E_N–ΔS (%) relations for t = 30 years.

addition, all active port numbers were decreased in DBV used diffusers under the same total head conditions of the circular port.

Fig. 1 describes for DBV12 condition before and after DBV use active and inactive ports for fully flow rate capacity and the same total head of diffuser. It is clear that when DBV used in a diffuser, its N_a value and diffuser length were dramatically decreased. On the other hand Fig. 2 shows dilution comparison between circular port and DBV port including diffusers for t = 30 years. Obviously when dilution levels have low values in circular port condition, all DBV dilutions also have lower dilutions than circular port dilutions. Dilution differences between DBV and circular ports were increased when the dilution values increased.

In Fig. 3, E_N–ΔS (%) relation was given taking into account ρ_a values and port depth, H. All curves of Fig. 3 were plotted for H = 20–50 m, from left-hand side to right-hand side. As seen in Fig. 3, the increasing values of receiving water density were increased for the

Table 2
Circular port and duckbill mounted diffuser characteristics summary for operation start (t = 0 year)

Nozzle type			Circular port				Duckbill check valve					Comparison	
Case no.	ρ_a (kg/m^3)	H (m)	E_N (m)	u (m/s)	N_a	S	E_N (m)	u (m/s)	N_a	N_i	S	ΔS	ΔS (%)
DBV1	1,015	20	1.82	3.55	4	90.69	1.82	8.28	2	2	95.48	4.79	5.28
DBV4	1,015	30	1.92	3.65	4	123.97	1.92	8.52	2	2	121.11	−2.86	−2.30
DBV7	1,015	40	2.00	3.72	4	163.08	2.00	8.67	2	2	145.33	−17.75	−10.88
DBV10	1,015	50	2.20	3.93	3	193.94	2.20	9.13	2	1	167.88	−26.05	−13.43
DBV2	1,025	20	2.01	3.74	4	97.60	2.01	8.74	2	2	97.77	0.16	0.17
DBV5	1,025	30	2.21	3.95	3	139.61	2.21	9.17	2	1	125.42	−14.18	−10.16
DBV8	1,025	40	2.40	4.11	3	176.77	2.40	9.54	2	1	151.81	−24.96	−14.12
DBV11	1,025	50	2.74	4.40	3	208.66	2.74	10.20	2	1	174.62	−34.03	−16.31
DBV3	1,035	20	2.16	3.89	3	104.31	2.16	9.04	2	1	99.50	−4.80	−4.60
DBV6	1,035	30	2.48	4.18	3	148.01	2.48	9.70	2	1	128.56	−19.44	−13.13
DBV9	1,035	40	2.96	4.57	3	181.59	2.96	10.60	2	1	153.65	−27.93	−15.38
DBV12	1,035	50	3.20	4.76	3	216.98	3.20	11.01	2	1	179.12	−37.86	−17.45

E_N values of the same flow rate capacity. By increasing the port depth, the E_N values were also increased. Under these conditions, the minimum and maximum dilution differences were found for ρ_a = 1,015 kg/m^3 and ρ_a = 1,035 kg/m^3, respectively.

For an operational starting time, t = 0 year, Table 2 shows the comparison of dilutions, jet velocities, and active port numbers. However, S and ΔS (%) values were obtained from lower flow rate of t = 0 year and, higher level of E_N values, because of less head loss of main pipe line with same total energy of whole marine outfall systems. DBV used dilutions were changed as ΔS (%) from 5.28 to −17.45 ranges comparing the circular ports. By Increasing H and ρ_a levels, ΔS (%) values were decreased as seen in Table 2. There were very few number of positive valued ΔS (%), which are ρ_a = 1,015 kg/m^3 and ρ_a = 1,025 kg/m^3, respectively, for H = 20 m.

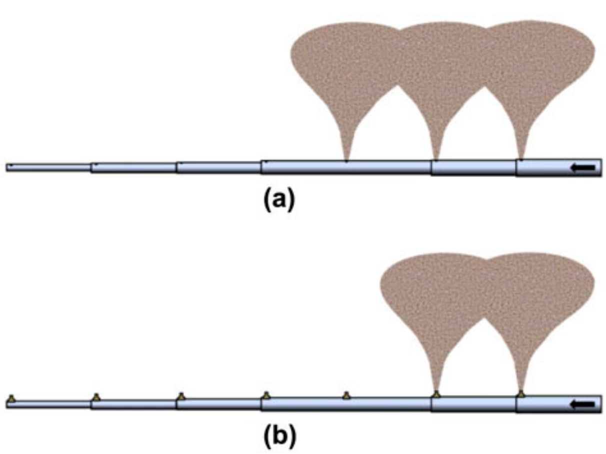

Fig. 4. Plan view of DBV 12 case t = 0-year diffuser: (a) circular ports and (b) DBV ports.

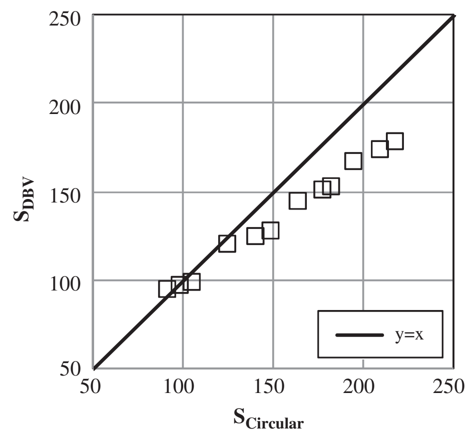

Fig. 5. Dilution comparison of circular vs. DBV port used conditions of same diffusers for t = 0 year.

Fig. 4 depicts the discharge conditions of t = 0 year for both circular and DBV ports. Because of the lack of wastewater flow rate and higher level of E_N, only three

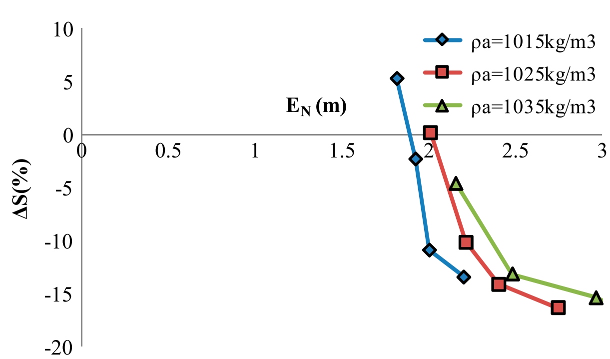

Fig. 6. E_N–ΔS (%) relations for t = 0 year.

circular ports or two DBV ports were active in $t = 0$ year. Fig. 5 has very close dilutions pattern like Fig. 2. Nevertheless, two of the DBV, S values were higher than circular values for $H = 20$ m. Fig. 6 also shows E_N–ΔS (%) relations for $t = 0$ year, emphasizing positive two ΔS (%) at $H = 20$ m condition. It should be considered that all E_N values were higher than $t = 30$ years, as previously mentioned.

4. Conclusion

During the operational processes, marine outfalls with multiport diffusers with sharp-edged ports need seawater intrusion and internal sedimentation protection. Especially thin-walled sharp-edged ports need such constructive protection. An elastomer check valve, "duckbill" check valve (DBV), maintains one-way flow and protects the diffuser, both seawater intrusion, and maintains high level of wastewater jet velocity. However, because of the requirement of extra energy in increased wastewater exit route of wastewater jet, minor head losses could decrease the dilution levels as mentioned by Duer and Salas [8], starting $H = 20$-m port depth or more. In this study, this indefinite amount of dilution loss after DBV mounted condition on the circular port was criticized. The analysis shows that for a long design lifespan for open circular ports need seawater intrusion and internal sedimentation protection, and active port numbers are very limited because of the lack of wastewater flow rate in the first operational years of the marine outfall systems.

For instance, for $t = 30$-year lifespan with increasing port depth, receiving water density, and total head of diffuser after DBV conversion of circular thin-walled sharp-edged ports dilutions could be decreased as ΔS (%) from −0.19 to −19.18 ranges. Even in the first operational years of the system, a very small amount of dilution improvement could be possible such as ΔS (%) = 5.28 at $H = 20$ m, and $\rho_a = 1{,}015\ \mathrm{kg/m^3}$. However, nearly all other estimations were shown that DBV use generally decreases originally designed initial dilution level. Finally, no matter how some dilution decreases that are defined in this study, DBV use should still be suggested in order to guarantee to keep the diffuser clean and operational.

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List of Symbols

ΔS	—	dilution difference between circular and DBV nozzle
ΔS (%)	—	dilution comparison percentage between circular and DBV nozzle
ρ_0	—	effluent density
ρ_a	—	receiving water density
c	—	diluted local pollutant concentration
c_0	—	source pollutant concentration
d	—	port diameter
E_N	—	total energy at the last port
f	—	Darcy–Weisbach friction factor
H	—	port depth
l	—	distance between subsequent ports
L_{main}	—	main pipeline length to diffuser
N	—	total port number of original diffuser for $t = 30$ years
N_0	—	served population for $t = 0$ year
N_{30}	—	served population for $t = 30$ years
N_a	—	active port number
N_i	—	inactive port number
Q	—	flow rate
Q_0	—	flow rate for $t = 0$ year
S	—	dilution
$S_{circular}$	—	dilution of circular port
S_{DBV}	—	dilution of duckbill check valve
t	—	operation year, lifespan
t_w	—	diffuser pipe wall thickness
u	—	jet exit velocity at port
v	—	velocity in diffuser pipe

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